

## METHOD AND APPARATUS FOR LOW OVERHEAD CIRCUIT SCAN

### BACKGROUND OF THE INVENTION

#### 1. Technical Field

[0001] The present invention relates in general to a field of computers, and in particular to movement of data in state holding elements. Still more particularly, the present invention relates to a method and system for moving scan data through a data buffer using a reduced number of latches.

#### 2. Description of the Related Art

[0002] Computing processor logic is typically made up of multiple clusters of processing logic and data latches that manipulates data according to machine instructions executed by the processing logic, or self-directed logic such as a programmable logic array (PLA) or a field programmable gate array (FPGA). A typical collection of logic and latches is shown in **Figure 1** as logic/latch array **100**.

[0003] Logic/latch array **100** is made up of multiple state holding elements **102** (typically latches) and logics **104**. Data bits are input into the top state holding elements **102** where the data bits are latched, and at a subsequent clock cycle are loaded into one or more logics **104**. The results of the operations of the logics **104** are then outputted to one or more state holding elements **102**, and so on until the final results are outputted at the bottom of the logic/latch array **100**. A chip is composed of many such blocks of logic and latches. A common desire when a chip is manufactured to test whether there were any defects in the manufacturing process that may cause function different from that which would result from defect free manufacturing. A test program of data bits, a set of test vectors, inputted into the top of logic/latch array **100** will output known predicted results, output or result vectors, from the bottom of the logic/latch array **100** after a known number of clock cycles if the logic/latch array **100** is working properly. For a given block of logic a prohibitively large number of vectors may be required to determine if the logic/latch block is suitably free from defects. This large number of vectors can result from logic that responds/changes only to a very specific set of inputs and is often called random resistant logic. One solution is to carefully choose the vector so as to get high coverage. Another solution

is to independently check smaller portions of the function. This can be accomplished by setting the state of the latches, clocking the system, and reading the results from the latches. The subfunctions between the latches should be less random resistant and also easier to determine vectors that cover a given percentage of the faults. Checking such intermediate calculations utilizes techniques such as level-sensitive scan design (LSSD), generalized scan design (GSD) test techniques, or simple scan design test techniques that enable testing at all levels of VLSI circuit packaging. The principles of the LSSD technique are described, for example, in U.S. Pat. No. 3,783,254, No. 3,784,907 and No. 3,961,252, all to Eichelberger and incorporated in their entirety by reference.

[0004] **Figure 2a** illustrates latch pairs **202**, analogous to the state holding elements **102** shown in **Figure 1**, that are used for scanning data out of a latch array **200** that holds intermediate results of operations performed by logics **104** as described above. (For purposes of clarity, note that **Figure 2a** omits representations of logics **104** shown and described in **Figure 1**.) To facilitate trustworthy scans, each latch pair **202** illustrated in **Figure 2a** includes a master latch **M202** and a slave latch **S202**. The slave latches **S202** are necessary to ensure that data is not lost through timing mishaps that could occur if data bits were to be passed directly from a first master latch to a second master latch. During a scan-out process, a data bit in a first master latch is first scan/latched to a first slave latch, which then scans the data bit to a second master latch, which then passes the data bit to a second slave latch, and so on until the data bit safely scans (passes) through the entire latch array **200**. As depicted in **Figure 2a**, the latch array **200** of master latches **M202** and slave latches **S202** is under the clocking control of a first clock (**A\_clk**) for the master latches **M202** and a second clock (**B\_clk**) for the slave latches **S202**. Thus, when a scan-out operation is performed, the data bits are scanned out in a serial serpentine manner as depicted, wherein the data bit in master latch **M202-1** scans to slave latch **S202-1**, which scans the data bit to master latch **M202-2**, which scans the data bit to slave latch **S202-2**, and so on until the data bit is finally scanned out of latch array **200** through/from slave latch **S202-x**.

[0005] Referring now to **Figure 2b**, there is depicted a block diagram of four master/slave latch pairs being scanned out. Assume in **Figure 2b** that instead of twenty master/slave latch pairs **M202/S202**, as depicted in **Figure 2a**, there are only four master/slave latch pairs **M202-1/S202-**

1 through **M202-4/S202-4** in a First-In First Out (FIFO) **206**, as depicted. At initial time “T1”, input queue **208** holds data elements “w, x, y, z,” each master latch **M202** holds a significant data bit (such as a result of an intermediate operations performed by some piece of logic), each slave latch **S202** is empty or in a “don’t care” state, and the output queue **210** is empty (or in a “don’t care state). At time “T2”, all the data bits are shifted into the available slave latches. Thus, data bit “A” scans from master latch **M202-1** to slave latch **S202-1**, data bit “B” scans from master latch **M202-2** to slave latch **S202-2**, data bit “C” scans from master latch **M202-3** to slave latch **S202-3**, and data bit “D” scans from master latch **M202-4** to slave latch **S202-4**.

[0006] Moving on to time “T3”, the data bits are shifted into the master latches either from slave latches or from the external queue. In addition a data bit will be shifted to the output queue. So, data bit “z” from input queue **208** shifts into master latch **M202-1**, data bit “A” scans from slave latch **S202-1** into master latch **M202-2**, data bit “B” scans from slave latch **S202-2** into master latch **M202-3**, data bit “C” scans from slave latch **S202-3** into master latch **M202-4**, and data bit “D” scans from slave latch **S203-4** into output queue **210**. (Note that input queue **208** and output queue **210** may also have master/slave latch pairs (not shown) as depicted for FIFO **206**.)

[0007] Continuing along the time line in **Figure 2b**, significant data bits are continued to be scanned out of FIFO **206** until time “T9”, at which time all of the leading data bits (w, x, y, z) originally in input queue **208** are scanned into FIFO **206**, and all of the significant data bits (A, B, C, D) are scanned out of FIFO **206** into output queue **210**.

[0008] The main purpose of the slave latches **S202** depicted in **Figure 2a and 2b** is to ensure that data is properly passed and scanned from master latch **M202** to subsequent master latch **M202** without being lost. However, as pipelines get finer, and the number of latches increases, the use of pulse latches and merged logic latches, which do not have an already available slave latch may become more common. Adding a dedicated slave latch to each master latch, if not already there, becomes very costly in terms of chip space and power consumption. Therefore, there is a need for a method and system of data scanning that do not require slave latches dedicated to each master latch in a logic/latch matrix

## **SUMMARY OF THE INVENTION**

**[0009]** The present invention is directed to a method and system for manipulating data in a state holding elements array. Process data is moved through the state holding elements array by a process controller. A separate scan controller scans data out of the state holding elements array by scanning data out of a group of cascaded latches where there are insufficient extra state holding elements in the group to enable normal scan. A multiplicity of local scan clocks are utilized to shift selected amounts of data only when a next state holding element in the group has been made available by clearing the contents of that next state holding element. In this way, any given latch, for the purpose of scan, is not a dedicated master or slave latch, but can act as either. This invention also addresses a circuit for the creation of the multiplicity of local clocks from a conventional LSSD clock source.

**[0010]** The above, as well as additional objectives, features, and advantages of the present invention will become apparent in the following detailed written description.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0011]** The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, where:

**[0012]** **Figure 1** depicts logic/latch array of state holding elements and processing logic;

**[0013]** **Figure 2a** illustrates an array of state holding elements having data serpentine scanned out;

**[0014]** **Figure 2b** depicts a single row of state holding elements having data scanned out using prior art master/slave latch pairs;

**[0015]** **Figure 3a** illustrates scanning out of data in a row of latches utilizing the present invention, in which no slave latches are dedicated to master latches;

**[0016]** **Figure 3b** depicts clock signals received in different state holding elements in a row to control the scan-out of data from the row;

**[0017]** **Figure 4a** illustrates a circuit used in a preferred embodiment of the present invention to create a sequence of clock signals from a split clock signal;

**[0018]** **Figure 4b** depicts the timing chart of clock signals created by the circuit illustrated in Figure 4a;

**[0019]** **Figure 4c** illustrates clock and input signals used to generate the clock signals depicted in Figure 4b;

**[0020]** Figure 5a depicts a preferred embodiment of the present invention, including an input register, an output register, a timing circuit and a state holding elements matrix for data to be scanned out;

**[0021]** Figure 5b illustrates a preferred passgate used to control passage of data between state holding elements during a scan out operation; and

**[0022]** Figure 5c is a block diagram of the preferred embodiment of the present invention.

## DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0023] With reference now to **Figure 3a**, there is illustrated an exemplary flow of data being scanned out of a row (i.e., cascaded group) of state holding elements shown as a FIFO (First In First Out) **302**. An input queue **308** (which may be of any form and may not use master/slave latches) holds leading data bits "w, x, y, z." Input queue **308** includes an input scan latch **312**, which holds the next bit of data to be scanned into FIFO **302** as described below. Input queue **308** may hold data created by an interrupt, a test scan, or any other data used by those skilled in the art for scanning into a shift register, FIFO or similar.

[0024] At time "T1", FIFO **302**, which includes four latches **304-1** through **304-4**, holds intermediate result data "A, B, C, D." At time "T2", the only data that can scan out of FIFO **302** is the data bit "D" in latch **304-4**, since output queue **310** is presumed to always be capable of accepting data being scanned out of FIFO **302**. At time "T3", data bit "C" is able to scan to latch **304-4**, which was made available at time "T2" when data bit "D" was scanned out of latch **304-4**. At time "T4", data bit "B" is able to scan out of latch **304-2** into empty latch **304-3**, and data bit "C" is able to scan out of latch **304-4** into output queue **310**. Data continues to scan out of input queue **308** (via input scan latch **312**) and out of FIFO **302** as illustrated until all of the intermediary result data (A, B, C, D) in FIFO **302** is scanned out to output queue **310**. The timing of this scan out of FIFO **302** can be visually conceptualized as cars pulling away from a traffic light (at times T1 through T5), driving down the road (at times T6 through T8) and stopping at another light (at times T9 through T12). When pulling away from a traffic light, a car can only move if there is an opening in front. Similarly, as cars pull up to a traffic light, spaces between cars are filled up as they come to a stop.

[0025] The timing for clocks in each of the latches **304-1** through **304-4** is shown in **Figure 3b**. Each depicted clock cycle describes the time at which one or more data bits are able to scan (shift) as shown in **Figure 3a**. The timing shown in **Figure 3b** is critical for accomplishing the pattern of data scanning shown in **Figure 3a**. A preferred circuit for accomplishing this timing pattern is shown in **Figure 4**.

[0026] As illustrated in **Figure 4a**, timing circuit 400 includes a B\_clock line 402 and an A\_clock line 404. A\_clock line 404 is connected to the enable input 412-1 of clock latch 406-1 and the input of clock AND gate 410-1 as shown. Control line 408 is connected to the input of first clock latch 406-1. The output of clock latch 406-1 is connected to the input of clock AND gate 410-1 and to the data input of second clock latch 406-2. B\_clock line 402 is connected to the enable input 412-2 of clock latch 406-2 and to the input of clock AND gate 410-2. Similarly, A\_clock line 404 is connected to the enable inputs 412-3 and 412-5 of respective clock latches 406-3 and 406-5 as well as the inputs of clock AND gates 410-3 and 410-5. Likewise, B\_clock line 404 is connected to the enable input 412-4 of clock latch 406-4 and to the input of clock AND gate 410-4. The output of clock latch 406-2 is connected to the input of clock latch 406-3 and the input of clock AND gate 410-2, the output of clock latch 406-3 is connected to the input of clock latch 406-4 and the input of clock AND gate 410-3, the output of clock latch 406-4 is connected to the input of clock latch 406-5 and the input of clock AND gate 410-4, and the output of clock latch 406-5 is connected to the input of clock AND gate 410-5 as shown.

[0027] The timing of the B\_clk signal on B\_clock line 402, A\_clk signal on A\_clock line 404, and the Control signal on control line 408, said signals shown in **Figure 4c**, result in the clock signals shown in **Figure 4b** when all clock latches 406 are initially latched to zero. For example, at time "Ta", the control signal is high, the A\_clk signal is high, and the B\_clk signal is low. This results in clock latch 406-1 latching a high signal when clocked by the A\_clk high signal, and thus clock latch 406-1 has a high output signal. This high signal is logically AND'ed in clock AND gate 410-1 with the A\_clk signal, resulting a high clock cycle as shown in **Figure 4b** for clock line 1 at time Ta. Since clock latches 406-2 through 406-5 still have their initial contents latched low, the clock lines 2-5 remain low (no clock signal) since the outputs of clock latches 406-2 through 406-5 are all low, which prevents a clock signal from either A\_clock line 404 or B\_clock line 402 from passing through clock AND gates 410-2, 3, 4 or 5.

[0028] Moving on to time "Tb" in **Figure 4c**, the control signal remains high, but now A\_clk is low and B\_clk is high. At time Tb then, clock latch 406-1 continues to output a latched high signal, but the A\_clock line 404 now is not outputting a clock signal, and thus the output of clock AND gate 410-1 is low (no clock pulse). Clock latch 406-2 received a high input from clock



latch **406-1** when clock latch **406-2** is enabled by the B\_clk signal from B\_clock line **402** at time Tb. Thus, the inputs to clock AND gate **410-2** are a high signal from the output of clock latch **406-2** and the B\_clk signal from B\_clock line **402**, resulting in a clock pulse output from clock AND gate **410-2** onto clock line 2.

[0029] At time Tc, the control signal, B\_clk and A\_clk are the same as at time Ta, and clock line 1 again has a clock pulse as at time Ta. In addition, clock latch **406-3** has now been enabled by the A\_clk signal to latch the high output of clock latch **406-2**, thus resulting in clock AND gate **410-3** outputting a clock pulse resulting from the high output of clock latch **406-2** and the A\_clk signal from A\_clock line **404**. Clock line 2, whose signal is tied to the B\_clk signal, remains low (no clock signal).

[0030] The staggering of the clock signals continues to propagate through to clock lines 4 and 5 as shown. Eventually, the control signal goes low, and the clock signals dissipate sequentially. That is, at time Tw, the control signal is low, and thus clock latch **406-1** outputs a low signal even when the A\_signal is high, since the clock AND gate **410-1** can not pass the A\_signal through to clock line 1. This results in no clock signal at time Tw.

[0031] Since the output of clock latch **406-1** is now low, then when clock latch **406-2** is enabled by the next B\_clk signal, clock latch **406-2** outputs a low signal, thus preventing any clock signal from passing through clock AND gate **410-2**, resulting in clock line 2 remaining low (and missing clock signal represented by dotted line). The output of clock latch **406-1** remains low as long as the control signal remains low, and thus clock line 1 continues to have no clock signal. The clock signals continue to dissipate due to the timed low output of the clock latches **406**, finally resulting in none of the clock lines (1-5) carrying a clock signal (at time Tz).

[0032] With reference now to **Figure 5a**, there is illustrated a preferred embodiment of the present invention, including timing circuit **400** and state holding elements matrix **500**. For purposes of clarity and illustration, **Figures 3a, 3b and 5a** are viewed and described together.

[0033] Timing circuit 400, along with input register 502 and output register 504, facilitate the scanning of data out of state holding elements matrix 500 in a manner consistent with that illustrated in Figures 3a and 3b. State holding elements matrix 500 includes multiple rows of state holding elements such as latches 304. For example, latches 304a-1, 304a-2, 304a-3 and 304a-4 combine to form a row of state holding elements analogous to FIFO 302 described in Figure 3a. Latches 304b-1 to 4, 304c-1 to 4, 304d-1 to 4, and 304e-1 to 4 each make up another row of state holding elements analogous to other FIFO's 302. For purposes of clarity, only the operation of the row of state holding elements identified in Figure 5a as FIFO 304a are discussed. It is understood, however, that the other rows of state holding elements (latches 304) are preferably scanning out other data simultaneously with data being scanned out of FIFO 302a.

[0034] As described above, latches 304a-1 to 4 together are identified as FIFO 304a. At time T1, latch 304a-1 contains data "A", latch 304a-2 contains data "B", latch 304a-3 contains data "C", and latch 304a-4 contains data "D". At time T2, a clock signal on clock line 1 allows data "D" to pass through passgate 506a-4 from latch 304a-4 into output register master latch M504-1, thus initiating the scanning of data out of FIFO 304a. At time T3, data "D" is scanned into output register slave latch S504-1 (while continuing to be stored in output register master latch M504-1), and a clock signal on clock line 2 allows data "C" to pass through passgate 506a-3 from latch 304a-3 to latch 304a-4. At time T4, a clock signal on clock line 1 allows data "C" to pass through passgate 506a-4 from latch 304a-4 to output register master latch M504-1 (while data "D" passes from output register 504, preferably out from output register slave latch S504-1). Also at time T4, a clock signal on clock line 3 allows data "B" to pass through passgate 506a-2 from latch 304a-2 to latch 304a-3.

[0035] At time T5, a clock signal on clock line 2 allows data "B" to pass from latch 304a-3 to latch 304a-4, and a clock signal on clock line 4 allows data "A" to pass from latch 304a-1 to latch 304a-2.

[0036] At time T6, a clock signal on clock line 5 allows data "z" to pass from shadow latch 312-1 to latch 304a-1, a clock signal on clock line 3 allows data "A" to pass from latch 304a-2 to

**304a-3**, and a clock signal on clock line 5 allows data "B" to pass from latch **304a-4** to output register master latch **M504-1**.

[0037] At time T7, a clock signal on clock line 4 allows data "z" to pass from latch **304a-1** to latch **304a-2**, and a clock signal on clock line 2 allows data "A" to pass from latch **304a-3** to latch **304a-4**.

[0038] At time T8, a clock signal on clock line 5 allows data "y" to pass from shadow latch **312-1** to latch **304a-1**, a clock signal on clock line 3 allows data "z" to pass from latch **304a-2** to latch **304a-3**, and a clock signal on clock line 1 allows data "A" to pass from latch **304a-4** to output register master latch **M504-1**. At this point in time, all significant data has been scanned out of FIFO **304a**, and subsequent scan steps are primarily for the purpose of re-loading FIFO **304a** and the other rows of latches in state holding elements matrix **500** for subsequent logical data processing.

[0039] At time T9, a clock signal on clock line 4 allows data "y" to pass from latch **304a-1** to latch **304a-2**, and a clock signal on clock line 2 allows data "z" to pass from latch **304a-3** to latch **304a-4**.

[0040] At time T10, a clock signal on clock line 5 allows data "x" to pass from shadow latch **312-1** to latch **304a-1**, and a clock signal on clock line 3 allows data "y" to pass from latch **304a-2** to latch **304a-3**. Note that FIFO **304a** is now "filling up" to remove any bubbles (empty or "don't care" latches) in FIFO **304a**.

[0041] At time T11, a clock signal on clock line 4 allows data "x" to pass from latch **304a-1** to latch **304a-2**.

[0042] At time T12, a clock signal on clock line 5 allows data "w" to pass from shadow latch **312-1** to latch **304a-1**, thus completing the "reloading" of the row of state holding elements identified as FIFO **304a**. As noted above, in a preferred embodiment, other rows of state holding

elements, identified as **304b-1 to 4**, **304c-1 to 4**, **304d-1 to 4** and **304e-1 to 4**, simultaneously scan other data through in a manner analogous to that described for FIFO **304a**.

[0043] When data (scan data) is not scanned out as described above, data (process data) is pushed through and processed by processing units **505**. Data is passed from latches **304** to processing units **505** and/or from one processing unit **505** to another processing unit **505** and/or from on latch **304** to another latch **304**. The movement of process data through latches **304** and processing units **505** is under the control of a process controller **512**, shown in **Figure 5c**. Note that while, for purposes of illustrative clarity, connections and data flow are shown as being vertical for process data and horizontal for scan data, it is to be understood that scan and/or process data is able to move between latches **304** and/or processing units **505** in any direction that other connections (not shown) to latches **304** and processing units **505** allow.

[0044] In a preferred embodiment, passgates **506** depicted in **Figure 5a** are single N type field effect transistors (NFET's) as illustrated in **Figure 5b** as opposed to a full complement pass gate with both and NFET and PFET. A full complement pass gate would require the clock signal and it's complement. When using NFET only passgate it is necessary to drive the gate of the FET above the voltage of the signal that is being passed. A level shifter of the standard art placed after the clock AND gate can perform this function.

[0045] Referring now to **Figure 5c**, there is depicted a block diagram of the preferred embodiment of the present invention. A scan controller **510**, incorporating timing circuit **400**, is coupled to elements matrix **500** to control the movement of scan data out of scan latches in elements matrix **500** as described in detail above. Also coupled to elements matrix **500** is a process controller **512**, which coordinates the processing of data by and through elements matrix **500**. That is, process controller coordinates the processing and movement of data through the processing elements in elements matrix **500**. Process controller **512** moves process data into and out of specified processing elements in a coordinated manner according to the architecture of elements matrix **500**.

[0046] Since concurrent control of elements matrix 500 by scan controller 510 and process controller 512 would result in havoc, controller coordinator 512 coordinates the mutually exclusive operation of scan controller 510 and process controller 512. That is, during normal process operations involving elements matrix 500, controller coordinator 512 enables process controller 512 while concurrently disabling scan controller 510. While scan controller 510 is disabled, process data is processed by the processing elements 505 in elements matrix 500 in a normal fashion. Alternately, when controller coordinator 512 disables process controller 512 and enables scan controller 510, process data no longer passes through processing elements 505, and the data in scan latches 304 is scanned out under the control of scan controller 510.

[0047] The present invention, as described in its preferred embodiment, is thus able to scan data out of a latch array, such as state holding elements matrix 500, without the need for slave latches for every latch being scanned. Thus, a smaller number of overhead latches needed are now within the state holding elements matrix 500. The present invention further affords a single elements matrix to have separate and distinct controllers, one for processing data and one for scanning out inter-process data between processing units 505.

[0048] It should be understood that at least some aspects of the present invention may alternatively be implemented in a program product. Programs defining functions on the present invention can be delivered to a data storage system or a computer system via a variety of signal-bearing media, which include, without limitation, non-writable storage media (e.g., CD-ROM), writable storage media (e.g., a floppy diskette, hard disk drive, read/write CD ROM, optical media), and communication media, such as computer and telephone networks including Ethernet. It should be understood, therefore in such single-bearing media when carrying or encoding computer readable instructions that direct method functions in the present invention, represent alternative embodiments of the present invention. Further, it is understood that the present invention may be implemented by a system having means in the form of hardware, software, or a combination of software and hardware as described herein or their equivalent.

[0049] While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in

form and detail may be made therein without departing from the spirit and scope of the invention.